Design and Modeling of Vacuum Pumping Systems for Laboratory Scale Applications

A Thesis

submitted by

SANDEEP ADDALA

(Roll - 213ME5442)

in partial fulfillment of the requirements

for the award of the degree of

Master of Technology

Department of Mechanical Engineering

National Institute of Technology Rourkela

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CERTIFICATE

This is to certify that the thesis entitled **"Design and Modeling of Vacuum Pumping Systems for Laboratory Scale Applications"** submitted by **SANDEEP ADDALA (Roll No:213ME5442)** in partial fulfillment of the award for degree of **Master of Technology** in **Mechanical Engineering** with specialization in **Cryogenics and Vacuum Technology** is a record of bonafide research work carried out by him under my supervision during the period 2014-2015. The thesis has fulfilled all the requirements as per the regulations of the Institute and in my opinion, has reached the standard needed for submission.

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Abstract

Vacuum is a condition where the pressures are below atmosphere. Based on the pressures vacuum can be classified into low, medium, high and ultra high ranges. Vacuum finds its applications in many areas including industry, space research, food processing. One should have knowledge on the generation of vacuum to understand its effects. This project mainly focuses on the experimental setup of the vacuum pumps. The study, design, construction and installation of vacuum pumping systems viz. Vacuum chamber, Rotary pump, Roots pump was done. The working of rotary and roots pumps was studied and a list proper and necessary components and accessories was prepared. The methods to calculate the pumping speed of a pump at a pressure range were studied namely constant volume and constant pressure methods. The experiments were carried out and observations are plotted in a graph. The concepts of leak detection were also studied. Finally, the project helps in establishment of vacuum technology laboratory at NIT Rourkela, giving a practical approach to the students dealing with the Vacuum Technology to understand the vacuum process and research can be continued.

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Chapter 1

Introduction

1.1 Introduction

Pressure and temperature are two important parameters in defining the state of a system and any changes in them leads to a change in the system. Pressure, when considered in a closed system, is the force acting on the system per unit area and the temperature gives the degree of heat in the system. The areas of thermal engineering and fluid mechanics study the change in the properties and state of the systems with change in these parameters. When the temperatures are reduced below -150^0C, the study of the behavior of the bodies is known as Cryogenics and study at reduced pressures is known as Vacuum Technology. The system undergoes a series of changes when it is subjected to low temperature and vacuum and it is of utmost important to analyze them.

Vacuum is defined as the state of low pressure and thereby low density when compared to that of ambient surrounding pressures. Generally, the system is said to be in the state of vacuum when the molecular density is below 2.5×10^{19} molecules/ cm^3 and the pressure below 300 mbar. The pressures below atmosphere i.e. from 1013 mbar to 1 mbar is classified as low vacuum, in between 1 mbar to 10^{-3} mbar as medium vacuum, as a high vacuum in the range of 10^{-3} mbar to 10^{-7} mbar and from 10^{-7} mbar to down as a ultra high vacuum. Many areas of science and technology find their applications in the vacuum environments. The vacuum ranges, pumps used, and applications are described in Fig.1.1.

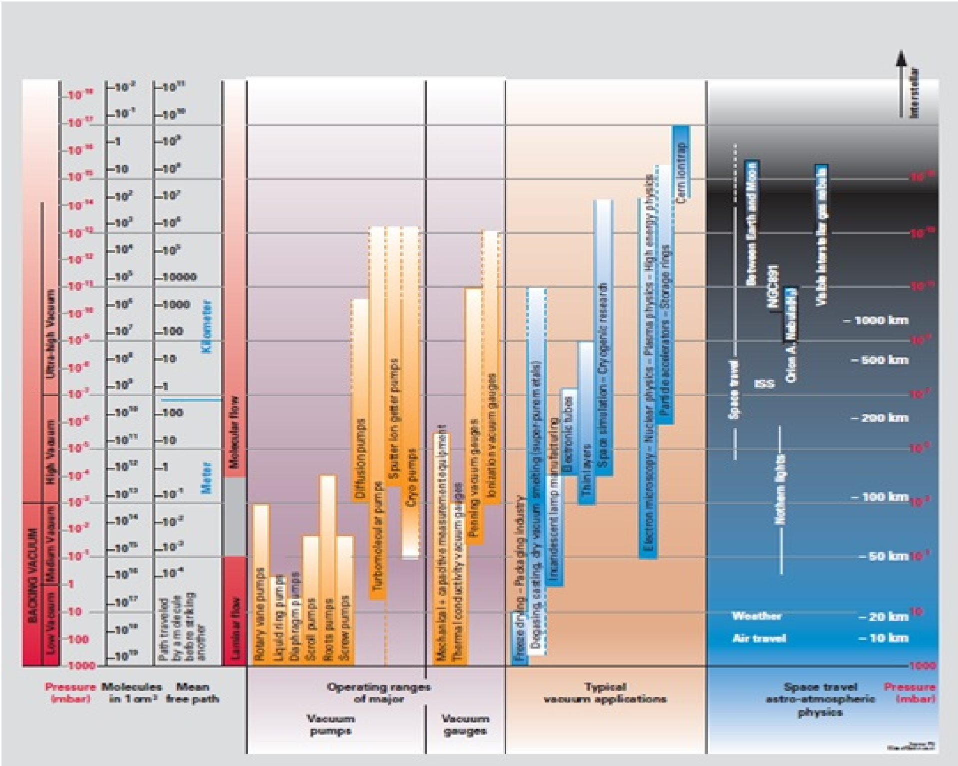

Figure 1.1: Vacuum Overview

The study of vacuum dates back to 1^{st} century B.C but the major breakthrough was with the development of vacuum pump in late 16^{th} century. Vacuum pumps which are the machines used to create vacuum pumps out the gases from the chamber or a body thus reducing the molecular density in it. Another mode of vacuum creation is by the entrapment of gas molecules or in other words immobilizing of the gas molecules either by adsorption or by cryo trap. This method is used in sorption and cryo pumps. As discussed above the vacuum is expressed in terms of pressure units i.e. mbar (mille bar). However, other units of pressure can also be used but the value remains unchanged.

$$\mathbf{1atm = 1.013\ bar = 760torr}$$

So, at vacuum conditions, the pressures are so low that we can take all the units to be almost same, i.e. at very low pressures, **1atm = 1bar = 1torr = 1000mbar**. Thus, mbar is the very common unit to express the vacuum.

In an ideal case, when a chamber is evacuated, the vacuum is clean and remains in this condition unless vented. Also, vacuum generation is the removal of gas molecules from the chamber. However, the realistic condition is a different scenario and is influenced by many processes and thus the chamber evacuation not only means pumping out the gas molecules, but also involves in overcoming the diffusion, desorption and many processes which are discussed below.

Processes influencing the real time vacuum systems:

1. **Contamination:** The vacuum chamber must be a cleaned surface to reach the required vacuum as quickly as possible. But, due to the pumping oil, dust particles; other suspended particles make the process slow. Hence, one should make sure that the surfaces should be as clean as possible at the time of installation of the vacuum equipment. Use of vacuum grease should be sparse and unnecessary usage is to be avoided.

2. **Condensation and Vaporization:** The states of matter of a substance are mainly a pressure and temperature dependent. As the pressure decreases in vacuum generation there may be a phase change and the particles

get adsorbed to the walls of the chamber. Hence, condensers are to be used to vaporize these particles which will be removed by pumping subsequently.

3. **Desorption, Diffusion, Permeation and Leaks:** The gases, water vapor, pumping fluids always gets absorbed and adsorbed by the chamber walls and connecting lines. At the time of pumping these gases are desorbed again into the chamber. This phenomenon spoils the level of vacuum attained and is not desirable. Also, at a high vacuum range the seals, and other plastic surfaces vents off or diffuses off the dissolved gases in them. Permeation and leaks allow the gases outside the chamber inside. Thus, a vacuum chamber is baked out to prevent these things and fine surface finish and machining is needed to avoid leaks.

4. **Venting:** When a process is done in vacuum, one should bring the chamber back to atmospheric pressure. In general practice, air is used for venting and this may lead to contamination with the particles in air. Hence, for proper maintenance, nitrogen gas is to be used for chamber venting. All these are summarized in the fig.1.2

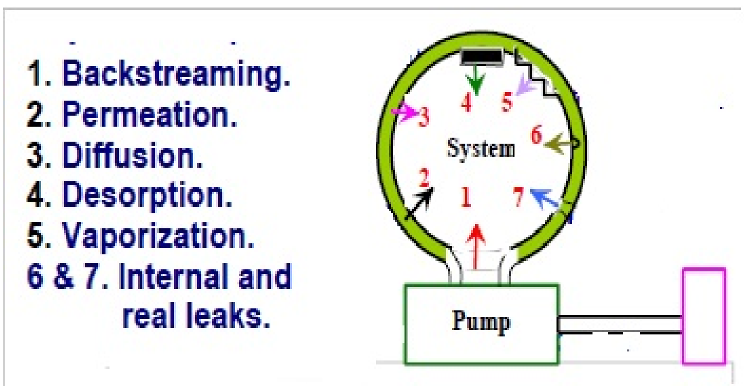

Figure 1.2: Influences on Real Time Vacuum Systems

The vacuum had gained much importance and is playing a major role in many areas of research, industry and manufacturing. The vacuum level is varied based on the need of the applications. A few are discussed below.

The vacuum applications include:

1. **Space Research:** In the outer space, the vacuum is of ultra high range and the radiation is more prevailed. So, the space shuttles, satellites, rockets and all other bodies traveling in space should with stand these environmental conditions. To design these equipment, a simulated vacuum environment to test the working of the same. Thus, vacuum plays a major role in space research.

2. **Food and packing industry:** Packaged food has taken a huge leap in the market and food industry needs to be more careful in providing their services. The food packed should be long lasting and needs to be packed in a careful environment to prevent any contamination. Vacuum is the best option and the packaged tins should be evacuated before. Thus, vacuum plays an important role in this food and packaging industry.

3. **Heavy industries:** The heavy industries use vacuum for specific processes like heat treatment, cold working, heating which needs a contamination free environment.

4. **Cryogenics:** Cryo fluids will be at a temperature much below the room temperature and they need a container offering best insulation to store. Vacuum is the best insulator because the mode of heat transfer is only radiation. Also, the cryogenic process need a controlled and clean environment and it is being offered by vacuum.

5. The vacuum is also used in the fields of microchip manufacturing, mechanical processes like brazing, thin film coatings, heat treatment, electron microscopy, aviation and many others.

Chapter 2

Literature Review

In the context of literature review, a few papers, patents and company catalogs were studied and some useful information was extracted which helped in defining the problem and in the design criterion for chamber design. It is important to understand the terms capacity, throughput and ultimate vacuum of a vacuum pump as they are the major guiding parameters in selection of the vacuum pumping system. Too small a system would result in insufficient or no process whereas to large a system would result in high capital cost and operating cost.

A lecture notes on vacuum technology by Prof. V.V. Rao[1] had explained the vacuum pumps and their working principles, methods of leak detection. A paper titled Selection of precise vacuum pump for systems with diverse Vacuum ranges by H.M.Akram[6] had explained the pumping parameters which help in deciding the vacuum pumps. Also, many company catalogs offered the criterion in pump selection. Many Indian and foreign companies[3,5] which are manufacturing and marketing the different vacuum components had mentioned the appropriate functional ranges for their product and this had helped me in estimating the requirements of the project.

A handbook of design by Roark[7] had given the formula which is used to calculate the thickness of the vacuum chamber and the other dimensions. The piping that connects the vacuum vessel to the vacuum pumping system plays a vital role in the overall performance of the system. Sizing of the pipe requires relatively complex calculations based on various factors like flow conditions, turbulent, steady-state, molecular, friction coefficient, Reynolds number etc. too small a pipe would have low conductance restricting the flow rates due to higher pressure drops across it and too large a pipe would increase the capital cost.

$$\mathbf{D=2.4(Q)}^{0.5}$$

Where Q is the pumping speed and D is the diameter of the pipe. This relation can be taken as a thumb rule in the pressure range of 10 100 Torr.

The catalogs of M/s Pfeiffer Vacuum[8], M/s Oerlikon Leybold Ltd[2], M/s Everest Blowers[4] had given the ideas on variable frequency control drive, leak detectors, pressure measuring devices, and instructions on healthy maintenance of the vacuum systems.

Chapter 3

Problem Definition and Objective

With the study on the applications of vacuum technology on industrial scale and the research being carried out with the help of vacuum technology, it is evident that a student of vacuum should have a clear idea on the generation of vacuum and the analysis of the pumping speed so that we can proceed with the process with a pump of suitable capacity. Thus, the designing of an experimental setup to study this phenomenon in a laboratory scale has become a prime importance. Modelling of a pumping system is needed to suit ones requirement and thus unnecessary parts; connections and fittings can be eliminated. The industrial applications with their own pumping stations had motivated me in designing a vacuum chamber to meet the requirement of a laboratory at an educational institution.

The pumping systems are designed by using the available pumps in the market and a work of modelling and assembling of these components with the vacuum chamber is being proposed here. An experiment on the calculation of pumping speed of a pump with pressure change is to be carried out and the results are to be plotted in a graph showing Pressure Vs Pumping speed.

Chapter 4

Vacuum Chamber and Components

4.1 Chamber Design

Vacuum chamber is basically a container which is to be evacuated by connecting it to a pumping system. T chamber can be of any shape viz. rectangular, cylindrical or spherical. Among these spherical is ideal for vacuum applications. But, due to the manufacturing limitations, cylindrical chambers with domed heads are preferred to spherical and other ones. The vacuum chambers are to be designed based on external pressure. The pressure vessels can generally withstand a pressure of 4 atm. This is based on internal pressure but the chamber cannot withstand even a 1 atm pressure externally. Hence, if proper care is not taken for the design, the chamber collapses and buckles axially.

Most general materials used for chamber design are glass, brass, copper, stainless steel, carbon steel. Glass is used for laboratory scale the most preferred glass is Pyrex glass because of its low thermal expansion. The Pyrex glass parts are to be joined by glass welding with the use of oxy hydrogen flame. The brass also proves to be a fine option for chamber material but cannot be used for high vacuum applications as the zinc content in the brass evaporates and contaminates thereby causing the delay in pumping of the chamber. Copper is a good chamber material and can be joined by soldering and is generally used for low vacuum regions. Carbon steels can be used for the chamber but all the oxide layers have to be scaled off before using it. Else, the oxides form the rust which in turn entrap the water vapor present and contaminates it. Thus, the carbon steel chambers can only be used for short span and is scrapped. A layer of aluminum and silicon monoxide can be used for the prevention but it needs to be recoated time to time.

The stainless steel is thus the most used material for ultra high vacuum applications and in precise SS-304 alloy is used. The chamber parts are Tungsten-inert gas welded and the surface finish is obtained by the sand blasting, grinding techniques. The weld should be done carefully and double pass if necessary is done to prevent the leakage. After the weld, a leak detection test is to be carried out to test the weld efficiency. All the parts of the chamber including the flanges are to be made of same alloy to have same coefficient of expansion and to prevent penetration. The cast materials are to be avoided for manufacturing the chambers as they have more porosity tending to leak and the rough surface of the cast enhances the absorption and adsorption phenomenon. The materials like zinc, cadmium, lead, sulfur cannot be used as chamber materials as they have higher vapor pressure to be used for vacuum applications.

The chamber, as discussed, is to be designed based on external pressure and the governing equation is given by Roarks formula

$$P = \frac{2E}{1-\mu^2}(\frac{t}{D})^3$$

Where, P is the pressure on the external side, i.e. 1 atm, D t are the diameter and thickness of the chamber, E, μ are the Youngs modulus and Poissons ratio of the chamber material respectively.

For a laboratory pumping system design, a chamber of 25 liters capacity was proposed with the dimensions of 300mm diameter and 350mm in length. Thus, by using the values E as 2×10^5 MPa, and Poissons ratio as 0.33 for stainless steel, Roarks relation, t can be found as 3mm. Considering the safety conditions, the thickness is taken as 5mm. Thus, a CAD design of a vacuum chamber is made with the use of outlets for feed-through and other connections. The chamber is considered to be a cylindrical pipe of 300mm diameter and a length of 350mm welded with a plate of 300 mm diameter and 10mm thick at the bottom. The top is closed with yet another plate of 370mm diameter and 10mm thick closed and locked with clamps. A groove of 3mm in width and 3mm in depth was made to accommodate the clamps at a distance of 3mm from the outer side. The flanged nipples of DN10, DN25 and DN40 were used for the outlets. The AutoCAD drawing of the proposed model is as follows in the fig.4.1.

The chamber is equipped with a DN40 flanged nipple, welded at a height of 130mm from the bottom for connecting the chamber to the pumping system. Two DN25 and two DN10 nipples at a height of 180mm from the bottom and at an offset of 30^0 on each side among them are joined to provide an access to the pressure gauges and any other necessary accessories. A DN10 nipple is welded at a height of 170mm from the top at the side of the chamber to fit it with a needle valve which is used for chamber venting. All the welds are to be carried out with

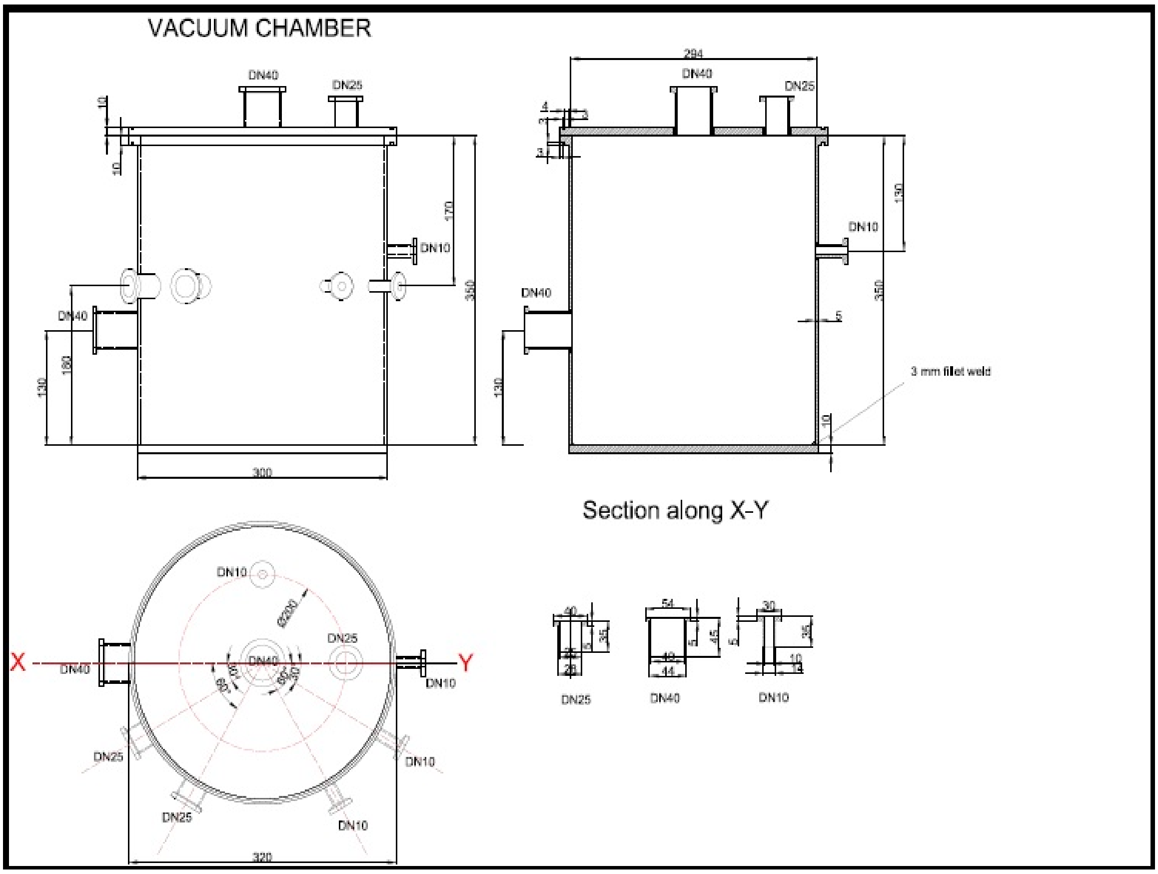

Figure 4.1: Chamber Drawing

utmost care and on the vacuum side of the chamber. All these welded nipples will act as the outlets for the important accessories to be connected. A chambers main function is to accommodate a process which needs to be carried out in the vacuum environment and thus it needs to an outlet or a door. Thus, the top plate is used for this purpose and is fixed with a DN40 nipple at the center and one DN25 and one DN10 nipples at a diameter of 200mm and at an offset of 90^0 in between them.

4.2 Vacuum Components

The vacuum accessories or the vacuum components are the most vital in a pumping system. All the connections, manipulations, controls and measurements are done by these components. The components used in these systems are discussed below.

1. **Centering O Rings:** The O rings are the sealing rings used at every connection. These are generally made of the sealing materials like viton, neoprene etc. These rings are mounted on a stainless steel rings which are used for centering and exact fitting in between the connections. The SS ring with neoprene ring forms a centering sealing. Neoprene rings are to be used for low and medium range vacuum, but as the vacuum increases, they fail to offer the sealing and at this stage metal rings are preferred.

2. **Aluminum Clamps:** Clamps are the locking devices. They close the connections with a centering ring in between them tightly and are fixed with a screw. When the connections are of KF type, a hinged clamp can be used, but when the connections and couplings are of LF type, claw clamps are to be used. Claw clamps are a two piece locking system provided with a bolt separately and are used for fixing large type flanges. Hinged type clamps are integrated with its own screw nut mechanism. The figure.4.2 shows the locking by the clamps with a centering in between them.

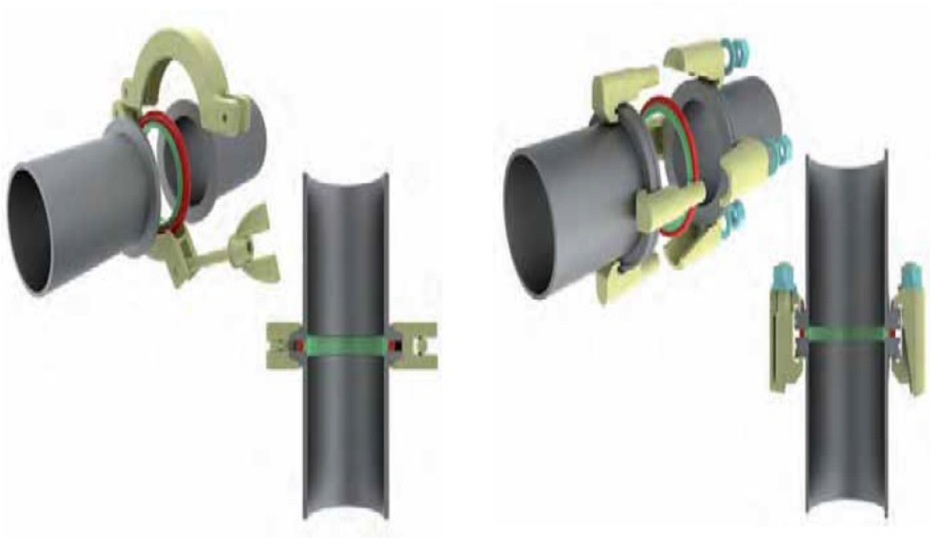

Figure 4.2: O rings and Clamps

3. **Flexible hoses:** flexible hoses are the pipe connections which are made of stainless steel and are flexible in nature. They can be used to connect the pumping station to the chamber or in between the two pumps within the pumping station. They are available in standard size and usually 1m in length with the ends flanged. The figure.4.3 shows the flexible hoses for vacuum fittings.

Figure 4.3: Flexible hoses

4. **Blank Flanges:** Blank flanges, also called as blind flanges, are the circular plates made of stainless steel which are used to close the unused fittings or paths. They are also available in standard sizes i.e. DN10, 16, 25, 40, 65, 80, 100. The thickness of the plate is nearly 3-5mm and is locked by KF couplings and clamps. The figure.4.4 shows the blank flanges used.

Figure 4.4: Blank Flange

5. **Reducers or Adapters:** Reducers or adapters the components made of stainless steel which reduces the size of the connections. If a DN40 pipe is to be connected to a DN25 gate valve, then a reducer of appropriate size is employed and the connection is made. If the size reduction is among the same class, i.e. KF KF or LF-LF, they are called reducers and if it in between different classes, i.e. LF-KF, then they are called adapters. They play a vital role in making a pumping system as it is not possible to have the required connections all the time. The figure.4.5 shows various reducers and adapters generally employed.

Figure 4.5: Reducer and Adapter

6. **Tee fittings and bends:** Sometimes, it is difficult to connect the system with flexible hoses alone. Though the term flexible, the hoses are not completely flexible and need a bend or 900 elbows. If there needs to be a split in the path, a tee fitting is employed of the size accordingly. The figure.4.6 of tee bend and elbow is shown below.

Figure 4.6: Tee and Elbow

7. **Valves:** Valves are the gateways to the connecting lines. There are different types of valve for different purposes and are listed as follows:

   (a) **Butterfly valves:** These valves open like a wing of butterfly and rotate only quarter of the revolution.

(b) **Ball Valves:** These valves are used both in pressurized pipes and in vacuum pipes. They have a sphere with a hole along one axis which is placed inside the casing. When the knob is rotated, the sphere opens and closes the path.

(c) **Needle Valves:** Needle valves allow only slight amount of fluid to pass through them. They are generally employed to control the flow to a small amount. In vacuum applications, they are used for chamber venting because the chamber cannot be opened to atmosphere suddenly. The figure.4.7 shows different valves used in vacuum applications.

Figure 4.7: Valves

Chapter 5

Rotary Pumping System

5.1 Introduction to Pumps and Pumping Systems

A basic vacuum pumping system consists of a chamber connected with a pump, vacuum gauge and other necessary accessories. The figure.5.1 describes a basic pumping system.

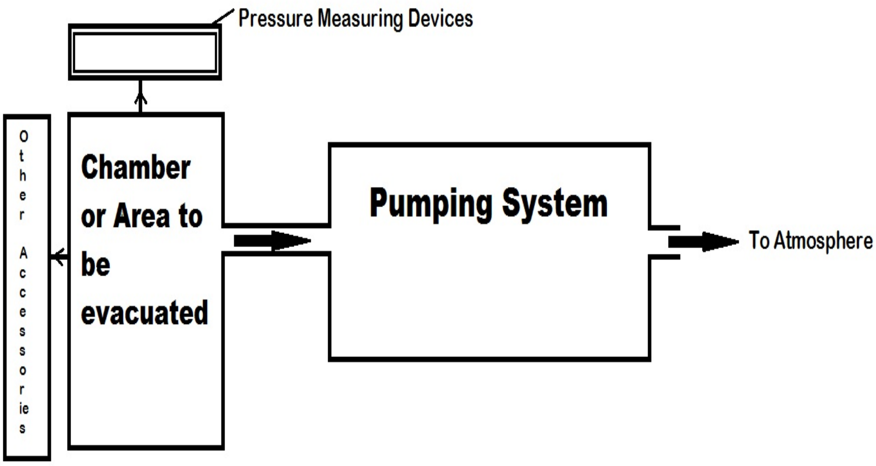

Figure 5.1: Basic Vacuum Pumping

Vacuum generation in a chamber needs the removal of the gases inside. This needs a mechanical device called a pump. These pumps when connected with the chamber, they either remove the gases out or immobilizes the molecules. There are different kinds of pumps available with different capacities in the market for this purpose. The types of pumps available are as follows.

1. **Displacement Pumps:** These types of pumps displace the gas inside the chamber by varying the chamber volume regularly and pumping the gases out directly to atmosphere. Rotary pump, roots pump comes under this category.

2. **Ejectors:** These pumps employ a working medium to pump out the gases. The working medium acts as a carrier to the gas molecules in the removal process. Diffusion pump falls under this category of mechanical pumps.

3. **Molecular pumps:** These pumps impart momentum to the gas molecules with the help of a set of high speed rotating blades on a set of stators. The gas molecules moving with high velocity are guided to the outlet and to atmosphere. Turbo molecular came under this category.

4. **Sorption Pumps:** They employ the technique of physic-sorption, chemi-sorption for the removal of gas molecules. They are entrapped by the adsorbing materials and then pumped out. Sorption pumps come under this category.

5. **Ion pumps:** Ionization of gas molecules is the prime factor in these types of pumps. Evaporation-ion and sputter-ion pumps fall under this category.

6. **Cryogenic Pumps:** these pumps immobilize the gas molecules by freezing them on t a cryo-cooled surface.

The types of pumps available for vacuum generation can be shown in the figure.5.2.

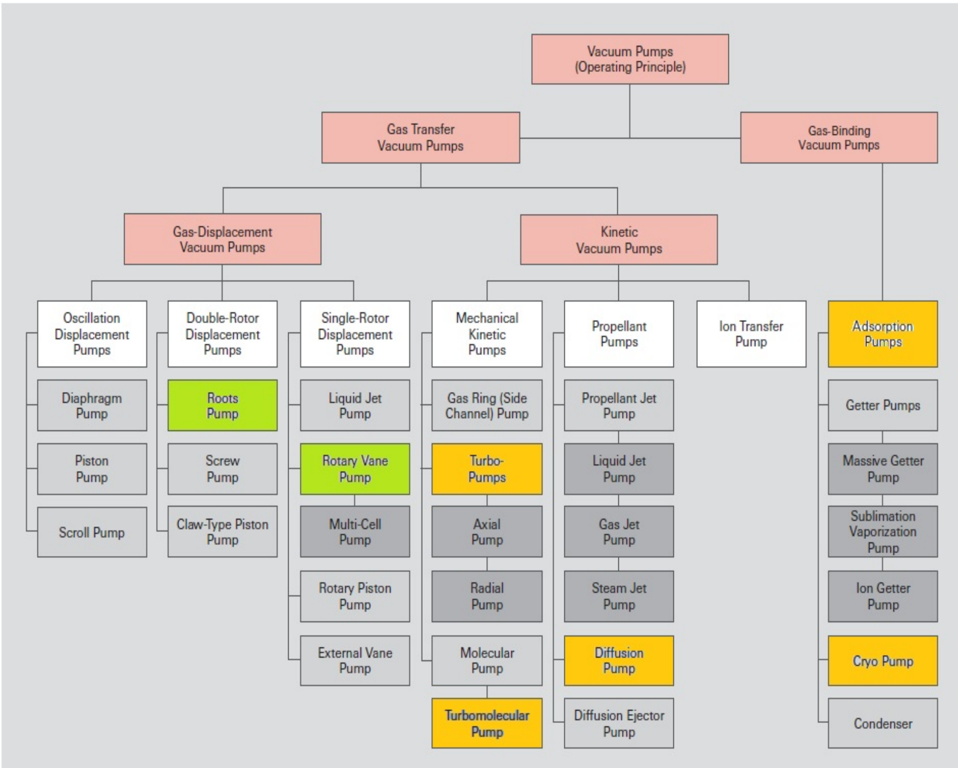

Figure 5.2: Vacuum Pumps

This work deals with the displacement pumps and their installation. Rotary pumping system and a Roots pumping system were installed and before considering the experimentation on both the pumps, a brief description of the pump and its working are discussed.

5.2 Rotary Pump

5.2.1 Introduction and Working Principle

A rotary vane pump or simply a rotary pump is the simplest of the positive displacement pumps. It is available in a single or double stage. It consists of a solid cylindrical shaft mounted eccentrically in a hollow cylindrical stator. A groove is made on the solid shaft along its diameter so that spring loaded vanes slide on the either side. The vanes are placed such that they always make a partition in the available volume in between the stator and rotor. The rotor touches the inner wall of the stator in between the inlet and outlet ports. Thus, when a vane completes one revolution, it sweeps the entire volume from the inlet port to the exhaust port. Hence, when the gas from inlet enters the volume in between the stator and rotor, the two vanes trap the gas in between them and sweep till the exhaust port. The other side of the exhaust port is maintained in an oil bath at atmospheric pressure. As the vanes compress the gas in the volume, the pressure is raised more than that on the opposite side and is pushed out. This process is repeated with the second and the cycle continues. It can be better understood by the following figure.5.3 which shows the process in a rotary pump.

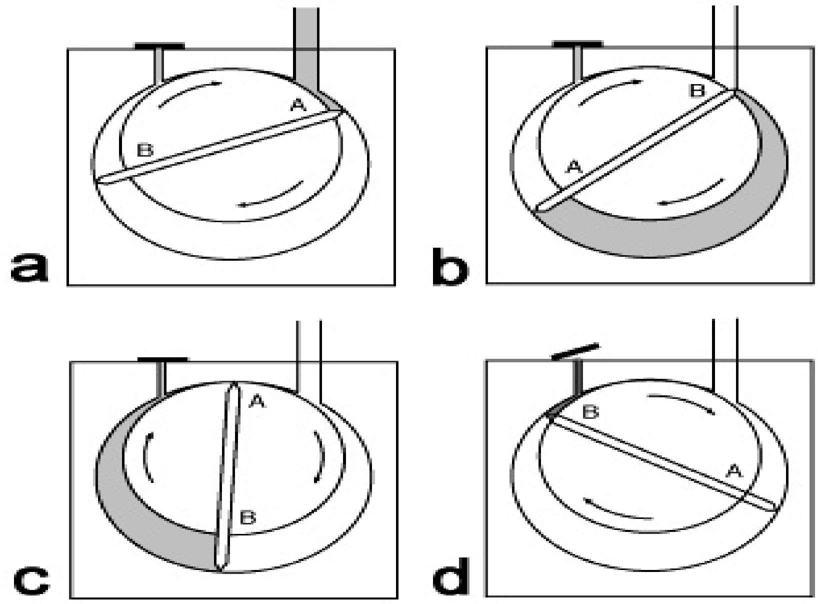

Figure 5.3: Rotary Pump Working

It can be seen that gas enters after A crosses the inlet port and is admitted till the B closes the port. Now, the entire volume of the gas in between A B is swept throughout till A reach the exhaust port. The exhaust port is opened now and the side B of the vanes pushes the gas out and the process repeats.

The rotary pump mainly constitute of rotor mounted on a shaft, a cylindrical chamber or stator, two spring loaded vanes, inlet tube for connecting the pump to the chamber, an exhaust port with a neoprene flap, gaskets, gas ballast valve assembly, an end plate with shaft bearing on one side at which a motor is connected and a simple end plate on the other end. The schematic exploded view of a rotary pump is seen in the figure.5.4.

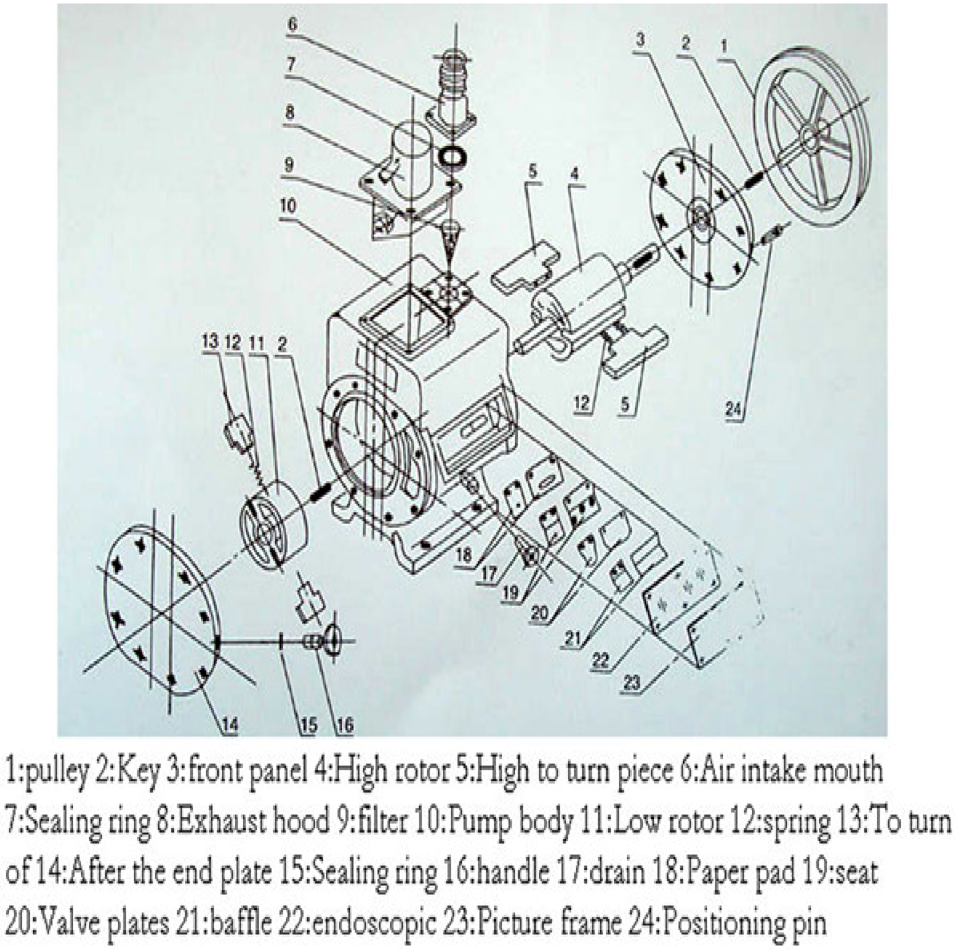

Figure 5.4: Exploded View

The neoprene flaps used at the exhaust port ensure that the gas flows in one direction only from the stator to the oil bath. It prevents any oil to back stream into the stator volume. A gas ballasting technique is used to remove any traces of vapours coming from the vacuum chamber. It is a valve which opens to atmosphere and allows the atmospheric air to pass through the pump. This air carries out the vapour traces out. The gaskets and oil seals separating the motor to the rotor ensure no leakage of oil. The pump is generally equipped with a solenoid safety valve to protect the vacuum environment against any sudden power failure.

5.2.2 Work Done

A rotary pumping system should consist of a chamber and a rotary pump connected by the proper piping and accessories. For an experimental setup, a rotary pump of 100 lps capacity is selected which is having inlet and exhaust ports of size DN25. A flexible hose of DN25 is thus used to connect the pump to the chamber. As the maximum vacuum that can be obtained by the rotary pump is 10^{-3} mbar, a pirani gauge is sufficient to give the pressure inside the chamber. A needle valve is provided to vent out the chamber at the end of the setup. The figure.5.5 gives the proposed setup for a rotary pumping system.

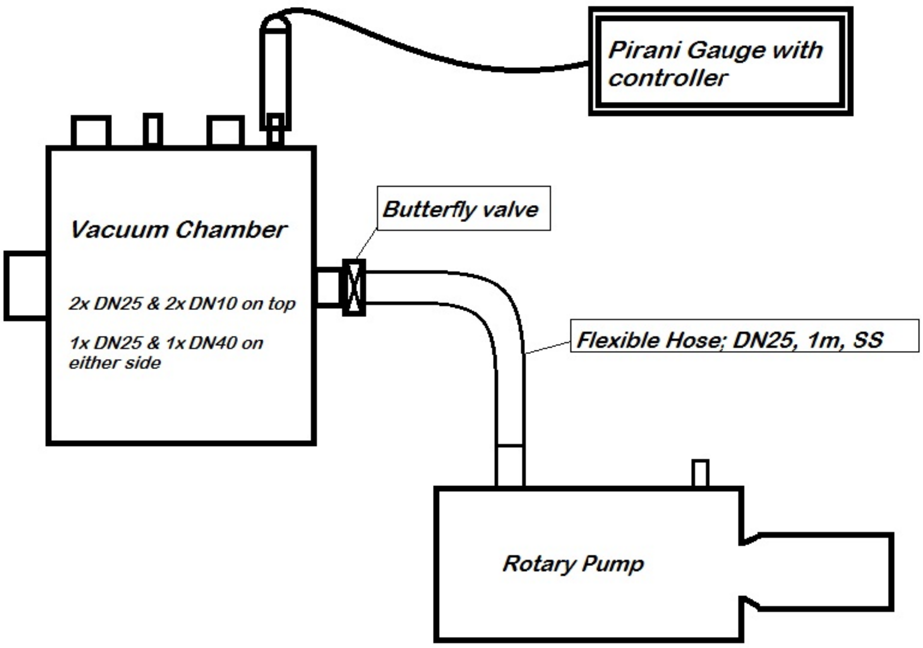

Figure 5.5: Proposed Rotary System

The components needed for the entire system include O rings, clamps, valves, piping etc. The components needed with the quantity needed are tabulated in table.5.1.

Sl.No	Component	Description	Quantity
1.	Centring O ring	DN40, Neoprene	1
2.	Centring O ring	DN25, Neoprene	4
3.	Centring O ring	DN10, Neoprene	2
4.	Hinged Aluminium Clamps	DN40	1
5.	Hinged Aluminium Clamps	DN25	4
6.	Hinged Aluminium Clamps	DN10	2
7.	Blank Flange	DN40, SS	1
8.	Blank Flange	DN25, SS	2
9.	Flexible Hose	DN25, 1m length, SS	1
10.	Needle valve	DN10,SS	1
11.	Butterfly Valve	DN25, SS	1

Table 5.1: List of Components for Rotary Pumping System

As the chamber is of stainless steel, all the components are chosen of the same material and as the ultimate vacuum is in medium range, the sealing can be accommodated by the neoprene rings. A butterfly valve is used to isolate the chamber from the pumping station when not in use.

All the components were purchased and a system was installed and is shown in the following figure.5.6.

Figure 5.6: Installed Rotary System

The experiment of pumping speed measurement can be done by two methods viz. Constant volume method and constant pressure method. The constant volume method is the easier of the two and is preferred generally. The constant pressure method needs a flow meter in addition to the components mentioned in table. The two methods are discussed below.

1. **Constant volume method:**

    (a) Proper precautions are to be taken and all the connections are to be checked before running the experiment. Proper oil level is to be maintained in the pumps.

    (b) All the ports are closed and the pump is switched on. The pump starts pumping out the gases and the pressure decrease can be observed on the pirani gauge display unit.

    (c) Time taken by the chamber to reach a particular pressure is to be noted. Different times for different pressures are obtained.

    (d) All the readings are to be tabulated and the pumping speed is calculated by the formula

    $$S = 2.303 \times \frac{V}{\triangle t} \times (\log(\frac{P_1}{P_2}))$$

    (e) The readings are to be plotted on a graph showing pressure ion X axis and pumping speed on Y axis.

2. Constant Pressure method:

    (a) The connections and oil levels are checked as in the constant volume method.

    (b) The pump is switched on and the pressure decreases with the time.

    (c) Fix a value of pressure in the range and by using a needle valve and flow meter allow the air to flow inside the chamber.

    (d) Adjust the flow such that the pressure in the chamber is maintained the same, i.e. fixed value all the time.

(e) Note down the flow rate at that pressure.

(f) Repeat the process for different pressures and tabulate the readings. The pumping speed is calculated by the formula

$$S = \frac{Q}{P}$$

(g) The results are to be plotted on a graph like in constant volume method.

Certain precautions are to be taken in doing the experiment of pumping speed calculation. They are:

1. Proper sealing of the connections should be ensured without any leaks.

2. The oil levels in the pumps should be maintained more than half its capacity.

3. All the valves are to be in closed position before switching on the pump. The gate valves or the needle valves are to be opened as per requirement.

4. During the maintenance of the pumps, clean and dust free environment is to be ensured to prevent contamination.

5. The seals and O rings are to be replaced from time to time to avoid leakages.

6. The gas ballasting and other cleaning operations are to be performed at regular intervals.

7. Leak testing is to be carried out regularly.

5.3 Experiment and Results

The experiment is carried out by constant volume method and the obtained readings are tabulated as shown in table.5.2.

Sl.No	PRESSURE	TIME	S
1	1000	0	1.6657
2	500	2	1.7034
3	100	5	1.6657
4	1	9	1.5457
5	0.9	11	1.6657
6	0.8	12	1.63852
7	0.75	13	1.613463028
8	0.5	17	1.56248
9	0.25	29	1.444056626
10	0.1	37	1.2683
11	0.075	45	0.899006476
12	0.05	69	0.422359488
13	0.025	128	0.293706432
14	0.01	178	0.16293
15	0.0075	320	0.050648252

Table 5.2: Reading of the Experiment

The tabulated results are plotted on a graph with pressure, P in mbar on X-axis and pumping speed, S in lps on Y-axis.As shown in figure.5.7

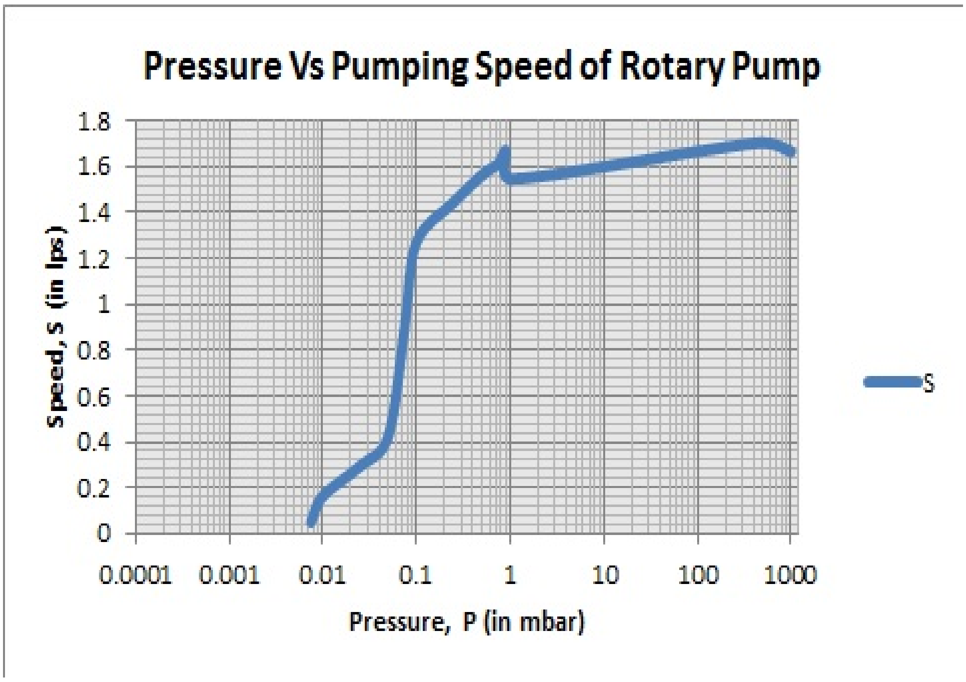

Figure 5.7: Pressure Vs Pumping Speed of Rotary Pump

From the graph, it is evident that the pumping speed of a rotary pump remains constant till the pressure reaches 1 mbar. However, there are slight fluctuation is the pumping speed. When the pressure is reduced below 1mbar, the pumping speed starts reducing drastically and finally reaches to zero when the pressure is of the order of 10^{-3}mbar. Thus, the rotary pump is more efficient in the range of 1000mbar to 10^{-2}mbar.

Chapter 6

Roots Pumping System

6.1 Introduction to Pumping System

Roots pump is another type of positive displacement pumps. It is also generally termed as roots blower and is a high capacity pump which can generate a vacuum of the order 10^{-5}mbar. The pump consists of a large casing which accommodates two figure-eight shaped lobes. These lobes are heavy and are counter rotating. These lobes neither touch each other nor the casing and the general clearance is about 0.25mm. This clearance is itself makes the closing of the system and also makes it a lubricant free operation. The entire system is driven by a single shaft connected to the motor and the lobes are connected by a series of gear mechanism.

The roots pump is more advantageous in handling heavy gas loads where a rotary or a diffusion pumps fail to be efficient. It also prevents the migration of the oil molecules of the rotary pump into the system when they are connected in series. Even though the roots pump can discharge the gases at atmospheric pressure, it is preferred to use a rotary pump as a backing pump. In general, the staging ratio, which is the ratio of pumping speed of the roots pump to that of

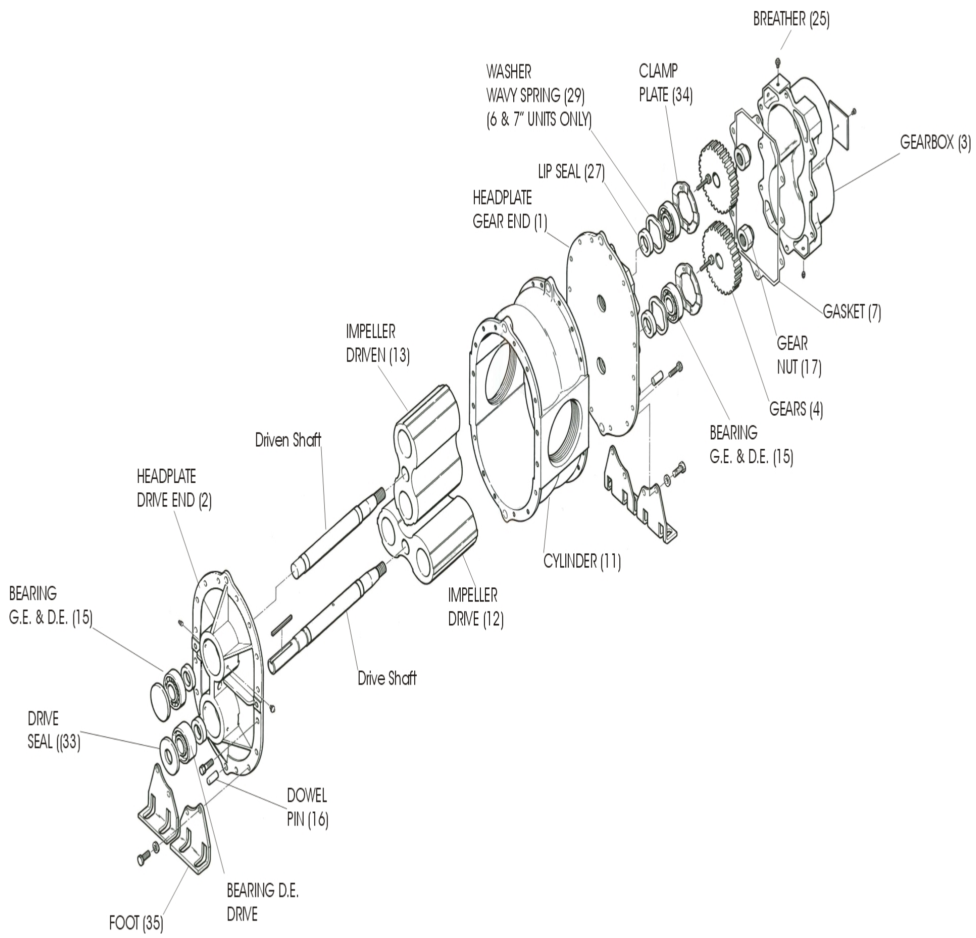

Figure 6.1: Exploded view of Roots Pump

rotary backing pump, is taken to be in between 2 and 10. Due to high molecular density at atmosphere, the roots pump cannot operate efficiently at the start. Thus, the backing pump also plays the role of roughing pump in bringing down the pressure to 100 or 1 mbar before the roots pump is started. However, as the roots pump takes some time to reach the full speed, both the pumps can be switched on at the same time and the pressure reaches the required value before the roots pump runs at full speed. The working of roots pump is explained by the figure.6.2.

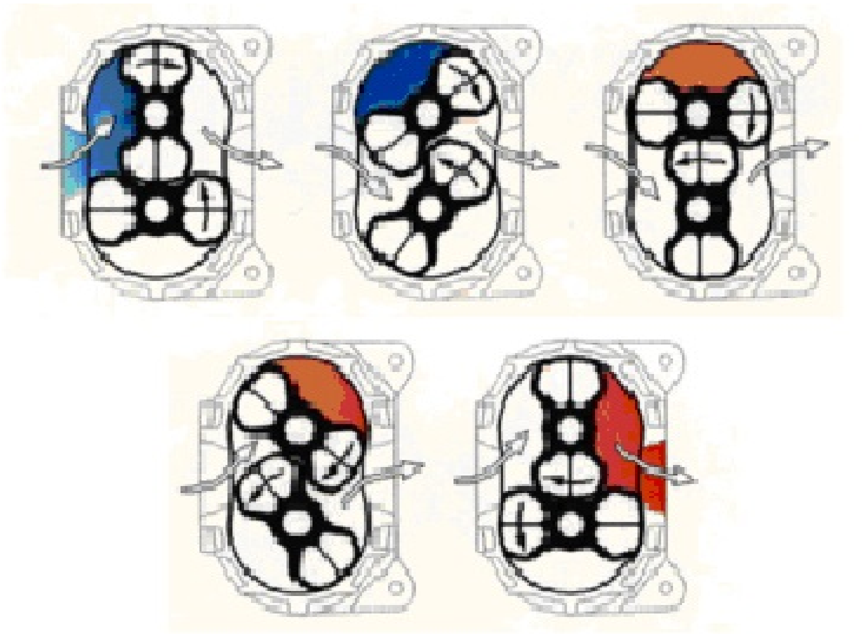

Figure 6.2: Working of Root Pump

The two lobes are placed such that one lies vertically and another in horizontal position. When the pump starts to run, some gas is trapped in between the lobs as shown in the figure. The lobes are rotated and the trapped gas is now in between a lobe and the casing wall. When the lobes are further rotated, the gas comes to the other side of the pump and is pushed out. When the gas is trapped in between the casing and the lobe, the lobe is now in vertical position where as the other lobe is in horizontal position. This is in the same way as in the initial case but in the other direction, and thus it also takes in the gas. This cycle is repeated and the gases are pumped out to the inlet port of backing pump. The commercial models available are robust in nature and their pumping speed ranges from a few hundreds of liters per minute to the order of 10^4 and 10^6 lpm. The ultimate pressure reached by the roots pump is of the order of 10^{-5} mbar and when if two such pumps are connected in series, slightly lower pressures can be obtained.

6.2 Experiment

The proposed system consists of a chamber connected to a roots pump and a rotary pump in series. The pipes of DN40 are used for all the connections. The proposed system with the connections and accessories is shown in the figure.6.3.

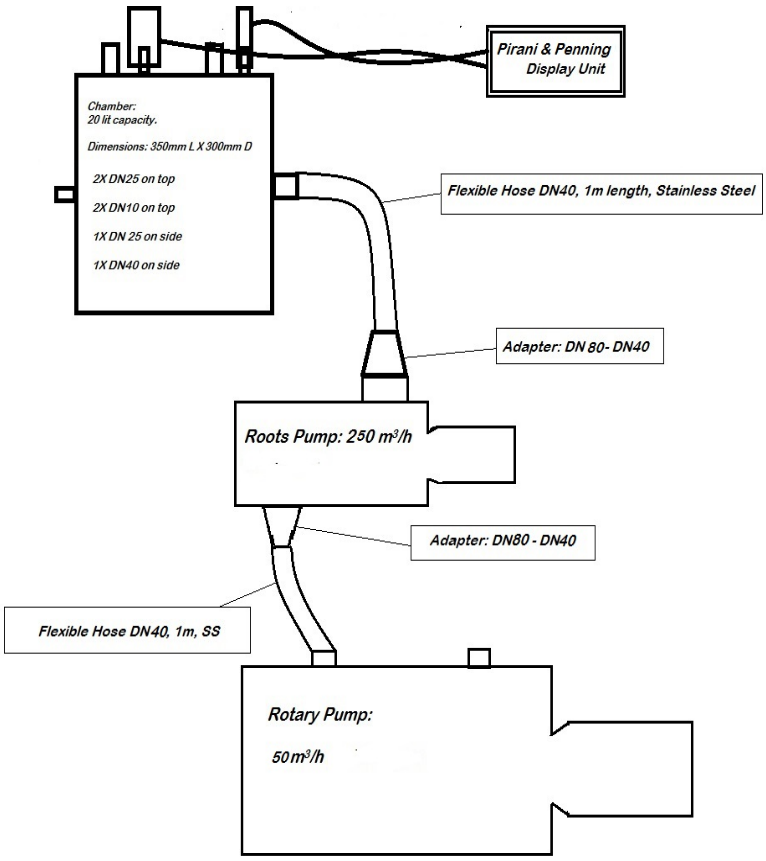

Figure 6.3: Proposed Roots System

The butterfly valve is used for isolation of the chamber in the same way as that of in the rotary system. A penning gauge has to be used as the pirani cannot detect the pressure changes below 10^{-3}mbar. Thus, the components needed for the system will comprise of reducers also, which are discussed earlier. The table.6.1 shows the components required for roots pump set-up.

Sl.No	Component	Description	Quantity
1.	Centring O ring	DN40, Neoprene	2
2.	Centring O ring	DN25, Neoprene	4
3.	Centring O ring	DN10, Neoprene	3
4.	Hinged Aluminium Clamps	DN40	2
5.	Hinged Aluminium Clamps	DN25	4
6.	Hinged Aluminium Clamps	DN10	3
7.	Reducer/Adapter	DN25-DN10, SS	1
8.	Blank Flange	DN25, SS	2
9.	Flexible Hose	DN40, 1m length, SS	2
10.	Needle valve	DN10,SS	1
11.	Butterfly Valve	DN40, SS	1

Table 6.1: List of Components for Roots Pumping System

As the capacity of the pump is more, i.e. $250m^3/h$, the conductance will be poor if a DN25 piping is used. Hence, a pipe size of DN40 is used for connecting the pump to the chamber as well as the backing pump. The chamber available is having only two DN10 ports, and hence a reducer is used to accommodate the penning gauge. The conductance of the DN40 pipe is also poor but it is of acceptable range. The installed system of roots pumping station is shown in figure.6.4.

Figure 6.4: Installed Roots Pumping System

The experiment was carried out by the method of constant volume and the readings are tabulated. Due to the low volume of the chamber and the high capacity of the pumping station, the ultimate vacuum will be reached in a few seconds. Due to the conductance of the pipes, leaks and other influences, the effective pumping speed will be of around 100 -150m^3/h.

The connections are made and the minimum leak is ensured. Both the pumps were switched on at the same time and the roots pump took almost 8 to 10 seconds to reach its full capacity. The time taken to reach the ultimate vacuum of 10^{-4}mbar is very less and of the order of 2-3 seconds. The readings are tabulated in the table.6.2.

Sl.No	PRESSURE	TIME	S
1.	1000	0	15.809
2.	150	3	15.80933321
3.	1	8	25.05317647
4.	0.0003	10	101.396601
5.	0.0001	12	13.73265361

Table 6.2: Reading of the Roots Experiment

The obtained results are plotted on a graph with pressure, P in mbar on X-axis and pumping speed, S in lps on Y-axis and is shown in the figure.6.5.

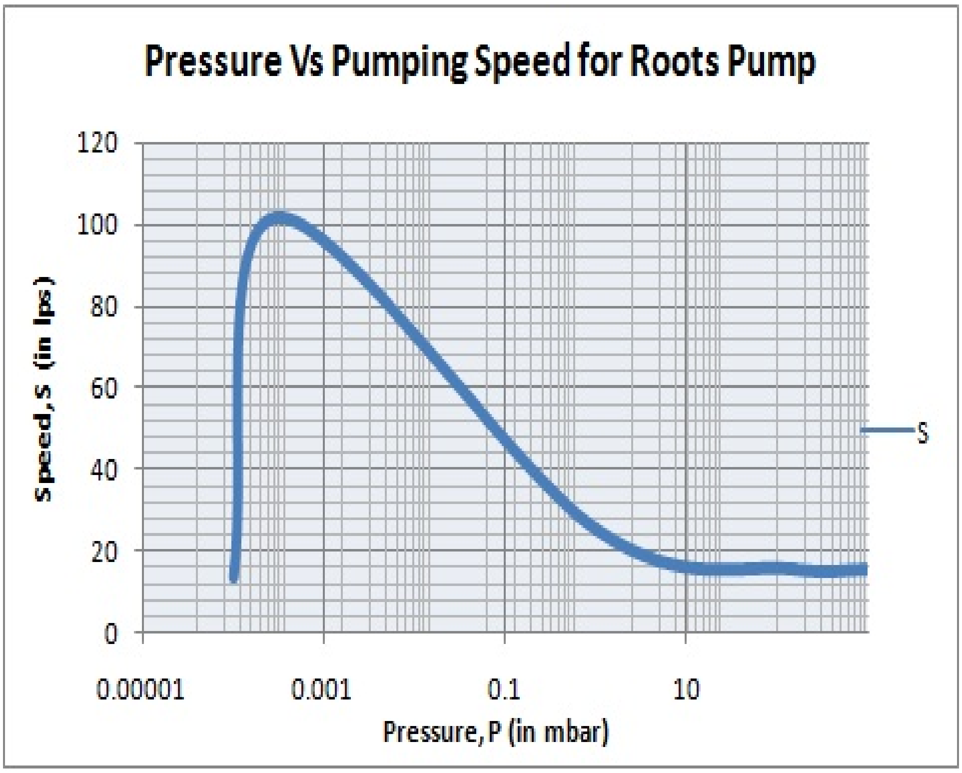

Figure 6.5: Pressure Vs Pumping Speed of Roots Pump

Chapter 7

Leak Detection

Whether it is a pressurized system or a vacuum system, leakage is the most common issue which can neither be avoided nor ignored. An ideal vacuum chamber should maintain its level of vacuum without a slight increase in the pressure forever when isolated. However, all the real situations, the pressure will not remain constant and is increased due to the presence of leaks. The leaks can be categorized into real leaks and virtual leaks. Real leaks allow the gases into the chamber from the external atmosphere where as the virtual leaks release the gases which are trapped from the corners, channels and envelope holes etc. the detection of a leak in vacuum system is of prime importance because, if the leak rate is more, the vacuum cannot be created or cannot be held.

There have come many methods of leak detection and are useful based on the ease of access and level of vacuum. All the leak detection techniques detect the leaks of the order of 10^{-2}mbar.l/s and above easily, but as the rate is further reduced, only a few techniques come in handy. The methods generally used are mentioned below:

1. **Soap Bubble test:** the soap solution is brushed at the expected area of leak on the test specimen which is filled with a gas preferably helium. Soap

bubbles can be seen if a leak is present.

2. **Leak covering:** In this method, a tape or plasticine is covered on the expected leak. If a leak is present, a sudden fall in pressure can be observed as the leak is closed.

3. **MSLD:** Mass Spectrometer Leak Detector is the most widely used method to detect the leaks in a vacuum system. It uses either hydrogen or helium gas in the process as they are the smallest available molecules. But, helium is most preferred because of its inert nature. MSLD is a standard residual gas analyser with a magnetic sector and is used to separate the two gases used. The operation of spectrometer can be classified into four steps namely

   (a) Creation of ions from the gas by electron impact

   (b) Acceleration of the ions till a known velocities and in a particular direction

   (c) Separation of ions based on the mass-to-charge ratio when subjected to an electric and magnetic arrangement in an analyser, and

   (d) Detection of these separated ions at the collector.

This provides an ion current signal related to the number density of the species which gives the leak rate. When the helium gas is sprayed on the leak, it passes through the leak and through the test probe of spectrometer, the gas is ionized and the collector gives the leak rate by the e/m ratio. The mass spectrometer with a helium probe gas is sensitive to a leak of $10^{-9} - 10^{-10}$mbar.l/s obtained at a pressure of 10^{-4}mbar.

A leak detection test can be performed in two ways and are called as spraying test and sniffing test. In spraying test, the test specimen is connected with a leak detector and helium gas is sprayed on to it at the expected leak area. The helium gas is detected by the detector if a leak is present. This method is very easy to perform and is mostly used in industries and research centres. Many commercial leak detectors are of spraying type and cost of maintenance is low. Other advantages of the spraying type test are high sensitivity, ease with local or integral test. Bombing method, which also similar to that of the spraying method is the only way to test the leak of sealed components with high sensitivity. The repeatability of this method is high and is very easy to integrate with the production line. The figure.7.1 shows the spraying test.

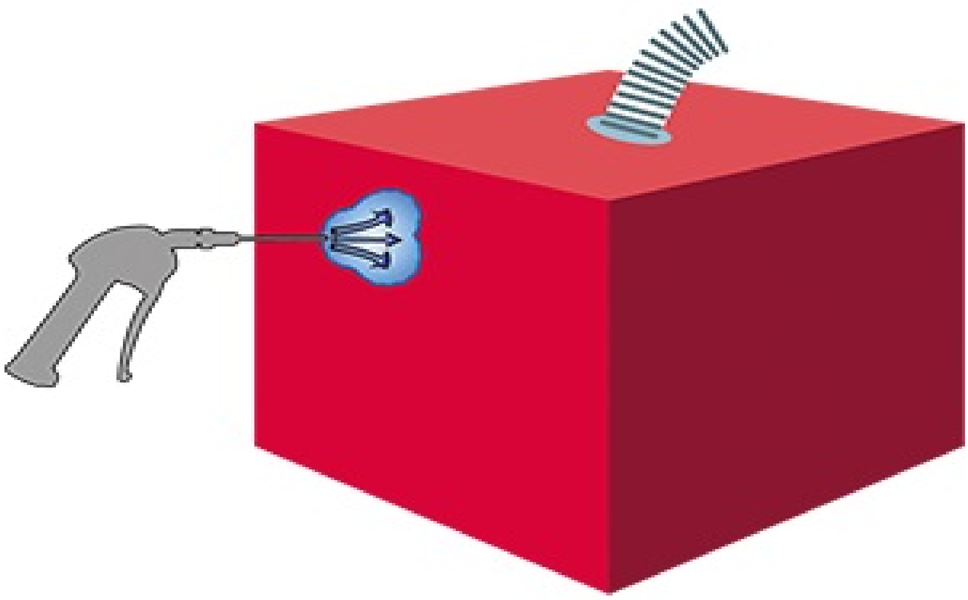

Figure 7.1: Spraying Test

The sniffing test is almost quite opposite to that of spraying test. In this method, the tracer gas is sent into the test part under pressure. Then the sniffer probe is moved over the expected areas and it senses any leak and the spectrometer gives the measurement of the leak. This method is mostly used for leak localization on pressurized parts. The major advantages of this method are that it is easy to perform and it is not necessary to put the test part under vacuum. This method is best suited for the parts which can withstand high pressures inside. The process of sniffing test is shown in the figure.7.2.

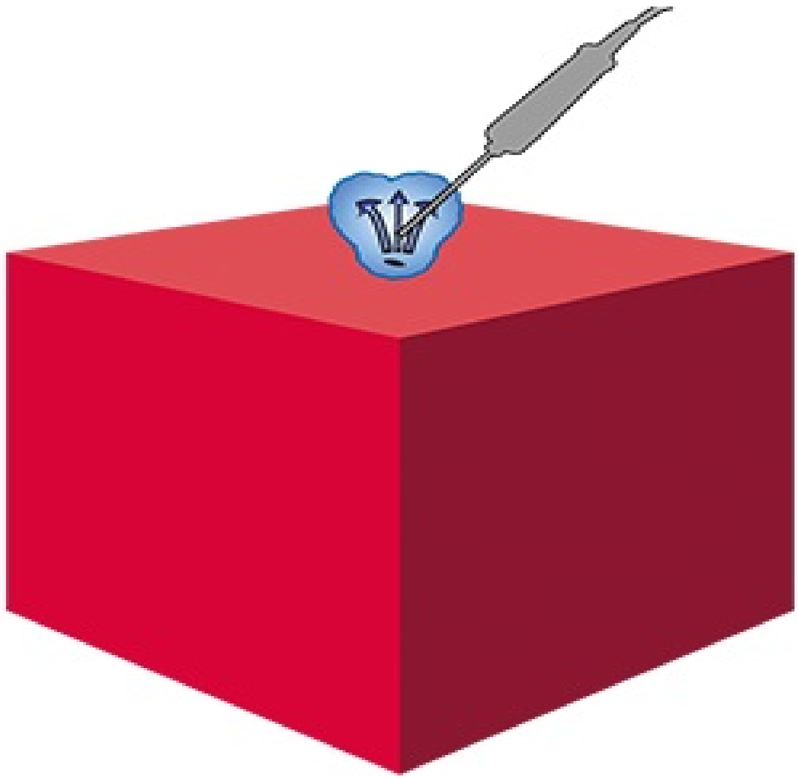

Figure 7.2: Sniffing Test

The portable leak detector, which is sufficient for the research purpose can measure a leak up to the range of 10^{-12}mbar.l/s and is an Alcatel make. It comprises of a rotary and turbo pump, an auto calibrated leak, a mass spectrometer and an electronic display unit. It calibrates itself before the test and the pipe sizing is DN25. The figure.7.3 shows the commercial leak detector that was procured.

Figure 7.3: Leak Detector

Chapter 8

Conclusion

This project gave the basic idea on the design of vacuum pumping systems including the chamber design, pump selection, accessories selection. It had also explained about the calculation of pumping speed with respect to pressure change and the behavior of the pump at various vacuum ranges is observed. It has concluded that the pump selection for an application is of utmost importance and the pipe sizing should be done by considering the conductance into account. It has also concluded that the pumping speed of the rotary pump reduces to a low value and subsequently to zero at the pressures of below 1mbar, whereas the pumping speed of roots pump is observed to be at its full capacity in between 1mbar down to 10-4mbar. The leak detection by a mass spectrometer with helium as tracer gas is studied and the importance of leak detection in vacuum technology is established. This project, had thus, helped in establishment of a vacuum technology laboratory at National Institute of Technology, Rourkela and had given the research scholars an opportunity to use the field of vacuum when needed, be it a heat treatment process, a brazing process, microscopy and many others.

Chapter 9

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